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Specification

1. Title of the Invention

CULTURE LIQUID COMPOSITION AUTOMATIC REGULATING METHOD AND CULTURE LIQUID COMPOSITION AUTOMATIC REGULATING APPARATUS

2. Claims

(1) A culture liquid composition automatic regulating method in a hydroponic culture apparatus for growing a crop by circulating a culture liquid, characterized in employing three or more comparing electrodes to measure respective membrane potential differences through an anion exchange membrane and a cation exchange membrane between a culture liquid in use and a reference culture liquid of an optimum condition for growing the object product, detecting the amount of decrease in a culture liquid concentration from one of the membrane potential differences, also detecting the pH variation in the culture liquid from the difference between the two membrane potential differences, supplying a culture liquid tank with a decreased culture liquid concentration with supplementary culture liquid from a base culture liquid tank by electric means to make up for the decrease, and correcting for a variation in pH thereby constantly maintaining the composition of the culture liquid at the optimum condition for the growth of the object crop.

(2) A culture liquid composition automatic regulating apparatus

characterized in that a container filled with a reference culture liquid of an optimum condition for the growth of an object crop and constituted entirely or partly of walls comprising anion exchange membrane, and a container constituted of a cation exchange membrane are arranged as to be in contact with the culture liquid in a culture liquid tank, with said ion exchange membrane wall portions between the interior of the containers and the culture liquid, a comparing electrode is immersed in the reference culture liquid in each container and comparing electrodes of a same kind are immersed, one in the culture liquid and the other on the other side of the ion exchange member constituting an entire wall or a part thereof of each container, and then each membrane potential is measured to detect a change in the composition of the culture liquid, and a solenoid valve, opened and closed according to the change thus detected is provided between the base culture liquid tank and the culture liquid tank.

(3) A culture liquid composition automatic regulating apparatus characterized in that a container with walls made from an anion exchange membrane and a cation exchange membrane without mutual contact, and which is filled with a reference culture liquid of the optimum conditions for the growth of an object crop, is so arranged as to be in contact with a culture liquid in a culture liquid tank across said ion exchange membranes, one or two comparing electrodes are immersed in the reference culture liquid in the container while two other comparing electrodes of a same kind are immersed in the culture liquid across the membrane wall portions from the comparing electrodes in the reference culture liquid respectively, a change in the composition of the culture liquid is detected by measuring the respective membrane potentials, and a

solenoid valve opened and closed by a signal that said change has been detected is provided between the base culture liquid tank and the culture liquid tank.

3. Detailed Description of the Invention

The present invention relates to a method for automatically regulating a composition of a culture liquid, namely concentration and pH of the culture liquid, employed for a hydroponic culture and a regulating apparatus therefor, and is to provide, in place of a prior method of detecting concentration of the culture liquid by an electric conductivity meter and a pH of the culture liquid by a pH meter and automatically correcting the concentration and the PH of the culture liquid by an electric operation, a method of detecting an amount of decrease of the concentration in the culture liquid and a PH change by a membrane potential difference between a reference culture liquid optimum for the vegetable product and an object culture liquid, thereby inexpensively and easily achieving automatic regulation of the composition of the culture liquid, and a regulating apparatus therefor.

Conventionally, as means for automatically controlling the concentration and the PH of the culture liquid in the hydroponic culture, there is employed a method of utilizing separate detectors such as an electric conductometer for the concentration of the culture liquid and a PH electrode for the PH. Such method, however, require separate detectors as mentioned above, and separate meters and control circuits therefor. Therefore the automatic control apparatus for the culture liquid composition in the prior method is not only bulky but also very expensive, and is thus hard to make practically usable. Also the culture liquid is prepared by dissolving inorganic neutral salts such as $Ca(NO_3)_2 \cdot 4H_2O$,

KNO_3, $MgSO_4$, $NH_4H_2PO_4$ etc. in water, and, if these dissolved ions are absorbed into the plant from the root in the same composition as that in the culture liquid, PH would show only a small change whereas the electric conductivity of the culture liquid would decrease. Therefore, an actual PH change in the culture liquid is induced by an imbalance of the aforementioned inorganic ions absorbed through the vegetable root. Consequently, the separate control of the concentration and the PH of the culture liquid as in the prior method cannot be considered an optimum culture liquid automatic regulating method also from the standpoint of the vegetable growth.

The present invention is a method of automatically managing the culture liquid, by utilizing a pair of comparing electrodes and detecting a change in the concentration of the culture liquid based on the potential difference generated between the electrodes opposite each other across an ion exchange membrane, namely a membrane potential difference, and also detecting a change in the PH of the culture liquid by comparing the absolute values of the membrane potential differences generated between the comparing electrodes across the ion exchange membranes of different polarities, thus being capable of inexpensively and exactly controlling the culture liquid by a pair of detectors. In general, in a system containing electrolyte liquids of different compositions across an ion membrane, in case the transport number of ions in the membrane is different from that in the electrolyte liquid, a potential difference between the solutions, namely a membrane potential difference Em, is generated and is represented by:

$$Em = \frac{RT}{F} \int_{a_i\,I}^{a_i\,II} \sum_i \frac{ti}{zi} d\ell nai$$

wherein R is a gas constant, F is a Faraday constant, T is an absolute

temperature, ti is the transport number of ions i in the membrane, zi is a charge of ions i, a_i^I and a_i^{II} are active amounts of the ion i in both solutions.

In case of an electrolyte solution of a relatively low concentration such as a culture liquid, almost exclusively only ions of one polarity can pass through the membrane, for example t- ≈ 1 and t+ ≈ 0 in case an anion exchange membrane is employed as the ion exchange membrane and t- ≈ 0 and t+ ≈ 1 in case a cation exchange membrane is employed as the ion exchange membrane. Therefore the potential difference between the sides of the ion exchange membrane, in a simple system such as:

$$M^+X^-(C^I)|\text{membrane}|\ M^+X^-(C^{II})$$

can be approximated by:

$$Em^+ \approx -\frac{RT}{F}\ell n\frac{C^I{}_{M+}}{C^{II}{}_{M+}} \qquad \text{for cation exchange membrane}$$

and

$$Em^- \approx -\frac{RT}{F}\ell n\frac{C^I{}_{X-}}{C^{II}{}_{X-}} \qquad \text{for anion exchange membrane,}$$

thus generating a membrane potential difference proportional to the logarithm of a concentration ratio between both solutions. In case of a simple concentration difference as explained above, there is obtained a relation $|Em^+| \approx |Em^-|$. However, in case the balance of $M^+X^-(C^{II})$ is upset for some reason and becomes $M^+X^-(C^{II} - \alpha) + M^+Y^-(\alpha)$ (wherein Y^- does not pass through the anion exchange membrane), there are obtained:

$$Em^+ \approx -\frac{RT}{F}\ell n\frac{C^I{}_{M+}}{C^{II}{}_{M+}} \qquad \text{and}$$

$$Em^- \approx -\frac{RT}{F}\ell n\frac{C^{I}_{x-}}{C^{II-\alpha}_{x-}}$$

and the relation $|Em^+| \approx |Em^-|$ no longer stands.

The change in the PH value of the culture liquid in the course of growing a crop is caused by the aforementioned reason. More specifically, in the stage of preparing the culture liquid by dissolving inorganic ions, constituting the nutrition source taken through the root of the plant and in the form of neutral salts such as $Ca(NO_3)_2 \cdot 4H_2O \cdot MgSO_4 \cdot 7H_2O$, KNO_3, $NH_4H_2PO_4$ etc., in a specified amount of water, these inorganic ions are contained by equivalent amounts of cations and anions. In the course of growing, the vegetable root does not absorb these inorganic ions stoichiometrically in the form of neutral salts, but absorbs anions such as NO_3^- ions in a certain growth stage and cations such as Co^{++} or K^+ in another growth stage, thereby causing an imbalance in absorption from the composition of the culture liquid. Therefore, the stoichiometry of inorganic ions contained in the culture liquid does not remain in the form of the neutral salts initially dissolved in water, but an electrical neutrality in the culture liquid is maintained by a change in the balance of ions H^+ and OH^- dissociated from water, namely in PH. In case the culture liquid causes not only a simple concentration decrease but also a concentration decrease involving an aforementioned composition change or a PH change, in comparison with the composition of the reference culture liquid, the membrane potential differences to the reference culture liquid across the ion exchange membranes, namely Em^- across the anion exchange membrane and Em^+ across the cation exchange membrane become different.

Utilization of the membrane potential differences as explained above

allows detection of the amount of change in the concentration of the culture liquid and the amount of change in the PH as inferred from the potential differences, thereby enabling an automatic management of the culture liquid composition.

A measurement of the membrane potential differences resulting from composition changes, based on the following combinations of neutral salts generally employed as the culture liquid, provided results as shown in the following table.

Reference culture liquid concentration

$MgSO_4 \cdot 7H_2O$	4 me/l,	$Ca(NO_3)_2 \cdot 4H_2O$	8 me/l
KNO_3	8 me/l,	$NH_4H_2PO_4$	4 me/l

comparing electrode: Ag/AgCl electrode

concentration ratio and composition ratio to reference culture liquid		membrane potential difference (mV) (potential difference for each reference culture liquid)	
		cation exchange membrane	anion exchange membrane
1	balanced composition	0	0
	K^+ decreased by 0.25 me/l, PH5.4	-0.24 mV	-0.02
	SO_4^{2-} decreased by 0.25 me/l, PH7.0	0	+0.23 mV
0.90	balanced composition	-2.08	+2.06
	K^+ decreased by 0.25 me/l, PH6.3	-2.35	+2.04
	SO_4^{2-} decreased by 0.25 me/l, PH7.1	-2.06	+2.34
0.80	balanced composition	-4.94	+4.93
	K^+ decreased by 0.25 me/l, PH5.1	-5.51	+4.90
	SO_4^{2-} decreased by 0.25 me/l, PH7.3	-4.92	+5.49

As shown in the foregoing table, measurements of membrane potentials of two ion exchange membranes allow instantaneous determination of concentration decrease from that of the reference culture liquid and culture liquid composition at that time, with a precision of 0.1 mV or better.

In the following, an example of a culture liquid composition automatic

regulating apparatus of the present invention will be explained with reference to a drawing. 1 indicates a culture liquid tank, and a culture liquid 2 in the culture liquid tank 1 is supplied by a pump 3 either continuously or intermittently by an operation of a timer 4, through a culture liquid supply pipe 5 to a culture tank 6, and returns through a circulating pipe 7 to the culture liquid tank 1. As nutrition components in the culture liquid 2 are absorbed by the plant in the culture tank 6, the culture liquid 2, maintained at a constant liquid level in the culture liquid tank 1 by a liquid level regulator 8, shows a gradual decrease in the concentration of the nutrition components and an imbalance in the composition, leading to a PH change. For detecting these changes, three comparing electrodes 9, 10, 11 of a same kind chosen among a group consisting of Ag/AgCl electrode, a calomel electrode, an oxide electrode, etc. are employed, wherein one comparing electrode 10 is immersed in a container 13 whose walls include a cation exchange membrane 31 and an anion exchange membrane 32 as ion exchange membranes without mutual contact, and which is filled with a reference culture liquid 12 of an optimum composition for the object vegetable of culture and is provided in the culture liquid tank 1 in such a manner that these ion exchange membranes are in contact with the culture liquid 2, while two other comparing electrodes 9, 11 are immersed in the culture liquid 2 so as to be opposed to the comparing electrode 10 across these ion exchange membranes, whereby membrane potential differences are detected between the comparing electrodes 9, 10 and the comparing electrodes 10, 11 respectively across the cation exchange membrane 31 and the anion exchange membrane 32. In case of a composition change in the culture liquid 2 as shown in the foregoing table, the correspondingly generated membrane potential

differences are transmitted, through leads 14, 15, 16 of the comparing electrodes 9, 10, 11 to a composition regulator 17. In case a difference is generated in the absolute values of the potential difference between the comparing electrodes 9, 10 namely the membrane potential difference on the cation exchange membrane and the potential difference between the comparing electrodes 10, 11 namely the membrane potential difference on the anion exchange membrane, and its value corresponds to a composition change requiring a correction, for example in case the potential difference between the comparing electrodes 9, 10 is larger to result in an imbalance of the composition with the PH of the culture liquid at the acidic side, a solenoid valve 19 is activated in response to a signal from the composition regulator 17 to pass the culture liquid 2, picked up by the pump 3, through a column 18 which is branched from the culture liquid supply pipe 8 and is filled with an anion exchange resin thereby elevating PH of the culture liquid 2 and returning it to the culture liquid tank 1. On the other hand, in case the potential difference between the comparing electrodes 10, 11 is larger to deviate the PH of the culture liquid to the alkaline side, a solenoid valve 21 is activated in response to a signal from the composition regulator 17 to pass the culture liquid 2 through a column 20 which is filled with a cation exchange resin thereby lowering PH. In this manner the composition regulator 17 outputs signals for activating the solenoid valve 19 or 21 for PH regulation of the culture liquid 2. In parallel, there is detected either of the two membrane potential differences between the comparing electrodes 9, 10 and between the comparing electrodes 10, 11 or an average thereof, indicating a level of decrease in the culture liquid concentration, and, in case of a decrease in the culture liquid concentration requiring a correction, signals from the composition regulator 17 open solenoid

valves 25, 26, 27 of base liquid tanks 22, 23, 24 to supply the culture liquid tank 1 with base liquids and the culture liquid 2 is made uniform by an agitator 29 driven by a motor 28.

When the difference between the potential differences between the comparing electrodes 9, 10 and between the comparing electrodes 10, 11 and both potential differences themselves become small within a tolerable range through these operations, all the solenoid valves 19, 21, 25, 26, 27 are closed by a signal from the composition regulator and the composition of the culture liquid 2 is corrected substantially same as that of the reference culture liquid 12. In case the object vegetable shows a change in the optimum composition of the culture liquid depending on the growth stages, the reference culture liquid 12 in the container 13 is changed to a culture liquid of an optimum composition for each growth stage, whereby the composition of the culture liquid 2 can be automatically regulated.

The foregoing example employs, as means for detecting the composition change in the culture liquid 2, three comparing electrodes 9,, 10, 11 of a same kind and a container 13 which is filled with a reference culture liquid 12 of an optimum composition for the growth of the object vegetable and of which a wall includes a cation exchange membrane 31 and an anion exchange membrane 32 without mutual contact, namely a configuration shown in Fig. 2(a), but it is also possible to employ detecting means utilizing two comparing electrodes 10, 10' in the same container 13 as shown in Fig. 2(b), or, as shown in Fig. 2(c) to separate the ion exchange membranes of different polarities to two containers 13, 13', to detect the cation membrane potential difference in the structure with the container 13 having the comparing electrodes 9, 10 and the cation exchange

membrane 31 and the anion membrane potential difference in the structure with the container 13' having the comparing electrodes 10', 11 and the cation exchange membrane 32.

Fig. 3 shows a control example of the culture liquid composition regulator 17. The cation exchange membrane potential difference Vk and the anion exchange membrane potential difference VA detected by the detectors are, as shown in Figs. 1 and 2, stabilized respectively through impedance converters 33, 34 and then made equal in the polarity of the potential difference through absolute value amplifiers 36, 36. The processed two potentials are passed through a subtractor 37, and, in case the two potential differences requiring PH correction are different from each other, one of the hysteresis comparators 39, 40 outputs a signal for elevating or lowering the PH. At the same time, the two processed potential differences are supplied to an adder 38 to transmit the average potential difference, calculated from the two potential differences, to a third hysteresis comparator 41, and, in case of the potential difference indicates that a concentration correction is required, there are generated signals for opening the valves 25, 26, 27 of the base liquid tanks 22, 23, 24. When the culture liquid is adjusted so that the difference between the two potential differences is within a permissible PH range and an average is a permissible concentration, the composition regulator 17 no longer outputs any signal, whereby the correction of the culture liquid composition is completed.

For regulating the PH of the culture liquid, there has been explained a method of PH correction by passing the culture liquid through an ion exchange resin layer, but any means capable of regulating the PH of the culture liquid by an electrical signal from a controller, such as a method of replenishing an acid or

an alkali from auxiliary tanks of acid and alkali or a method of executing electrolysis through an ion exchange membrane, is applicable to the culture liquid composition automatic regulating apparatus of the present invention.

As will be apparent from the foregoing example, the culture liquid composition automatic regulating method of the present invention and the regulating apparatus therefor, capable of detecting the concentration and PH of the culture liquid at the same time and executing correction of each, enables an inexpensive regulation with a less bulky apparatus, and thus is of large industrial value.

4. Brief Description of the Drawings

Fig. 1 is a structural view of a culture liquid composition automatic regulating apparatus showing an example of the present invention, Fig. 2(a), (b) and (c) are structural views respectively showing different examples of the culture liquid composition change detector in the regulating apparatus, and Fig. 3 is a block diagram of a composition regulator of the regulating apparatus.

1 culture liquid tank

2 culture liquid

3 pump

4 timer

5 culture liquid supply pipe

6 culture tank

7 circulating pipe

8 liquid level regulator

9, 10, 10', 11 comparing electrode

12 reference culture liquid

13, 13' container

14, 16, 18 leads

17 composition regulator

18, 20 column

19, 21, 25, 26, 27 solenoid valve

22, 23, 24 base liquid tank

31 cation exchange membrane

32 anion exchange membrane

33, 34 impedance converter

35, 36 absolute value amplifier

37 subtractor

38 adder

39, 40, 41 hysteresis comparator

[Fig. 3]

PH increase

PH decrease

concentration increase

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（全 6 頁）

⑤4培養液組成自動調整方法および培養液組成自動調整装置

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明　細　書

1．発明の名称

培養液組成自動調整方法および培養液組成自動調整装置

2．特許請求の範囲

(1) 培養液を循環して作物を育成する水耕栽培装置において、3本以上の照合電極を用い、使用中の培養液と対象作物の生育に最適条件の基準培養液の間にアニオン交換膜およびカチオン交換膜を介して各々の膜電位差を照合電極により求め、どちらかの膜電位差により培養液濃度減少量を検出し、かつ2つの膜電位差間の差により培養液のPHの変動を検出し、電気的手段により、培養液原液タンクから、培養液濃度減少分を培養液槽中に供給すると共に、PHの変動分を補正して培養液組成を常に対象作物の生育に最適の条件に保つことを特徴とした培養液組成自動調整方法。

(2) 対象作物の生育に最適条件の基準培養液で満たされかつ一部または全体がアニオン交換膜の壁よりなる容器およびカチオン交換膜の壁よりなる容器を培養液槽中の培養液と上記各イオン交換膜壁を介して接するように配し、各容器内の基準培養液中に各々照合電極を浸漬すると共に、各容器壁の一部または全体を構成するイオン交換膜を介して培養液中に同種の照合電極を対向させて浸漬し、各々の膜電位を測定して培養液組成の変化を検出し、この検出信号により開閉する電磁弁を培養液原液タンクと培養液槽の間に設けたことを特徴とする培養液組成自動調整装置。

(3) 対象作物の生育に最適条件の基準培養液で満たされかつアニオン交換膜およびカチオン交換膜が互に接することなく壁を構成している容器を培養液槽中の培養液と上記各イオン交換膜壁を介して接するように配し、この容器内の基準培養液中に1本または2本の照合電極を浸漬すると共に、これと同種の他の2本の照合電極を各々の膜壁を介して基準培養液中の照合電極と対向させて培養液中に浸漬し、各々の膜電位を

測定して培養液組成の変化を検出し、この検出信号により開閉する電磁弁を培養液原液タンクと培養液槽の間に設けたことを特徴とする培養液組成自動調整装置。

3．発明の詳細な説明

本発明は水耕栽培に用いる培養液の組成すなわち培養液濃度およびPHを自動的に調整する方法とその調整装置に関するもので、従来行なわれていた電気伝導度計により培養液濃度を、さらに、PH電極により培養液のPHを検出し電気的な操作により培養液濃度およびPHを自動的に補正する方法にかえて、作物に最適条件の基準培養液と対象培養液間の膜電位差を利用して培養液濃度の減少量およびPHの変化を検出することにより、安価かつ容易に培養液組成を自動調整する方法とその調整装置を提供することを目的とする。

従来、水耕栽培における培養液の濃度およびPHを自動的にコントロールする手段としては、培養液濃度に対しては電気伝導度計を用い、またPHに対してはPH電極を用いるというように別々の検出端を用いた方法が用いられている。しかし、このような方法においては、上記のように別々の検出端が必要であり、それに伴いメーターおよび制御回路も別々に備えねばならない。そのため従来の方法における培養液組成の自動制御装置は容積をとるばかりでなく、非常に高価なものとなり実用には供し難い欠点を有していた。さらに培養液は水に$Ca(NO_3)_2 4H_2O$, KNO_3, $MgSO_4$, $NH_4H_2PO_4$等の無機の中性塩を溶解して調整したものであるためにこれら溶解したイオンが培養液と同組成にて植物根から吸収されるのであれば培養液の電気伝導度は減少するが、PHは微小な変化でおさまるはずである。したがって、実際に引き起される培養液のPH変化は植物根から吸収される上記無機イオンの不均衡から生じるものである。そのため、従来の方法のように培養液濃度とPHを分離してとらえて管理したのでは、作物育成の上からも最適な培養液組成自動調整方法とは言い難い。

本発明は、1対の照合電極を用い、イオン交換膜を介して両電極間に生ずる電位差すなわち膜電位差により、培養液濃度の変化を検出すると同時に、極性の異なるイオン交換膜を介した照合電極間に生ずる膜電位差の絶対値の大小を比較することにより培養液PHの変化をも検出して培養液を自動的に管理する方法であり、1対の検出端により安価かつ正確に培養液をコントロールすることが可能である。すなわち、一般的にイオン膜を介して組成が異なる電解液がある系においては、膜中におけるイオンの輸率が電解液中の値と異なる場合、両溶液間には電位差すなわち膜電位差 E_m が生じ、その値は

$$E_m = \frac{RT}{F}\int_{a_i^{I}}^{a_i^{II}} \sum_i \frac{t_i}{z_i}\, d\ell n a_i$$

で表わされる。ただしRは気体定数、Fはファラディー定数、Tは絶対温度、t_iはイオンiの膜中の輸率、z_iはイオンiの電荷、a_i^{I}, a_i^{II}は両溶液中のイオンiの活量である。

いま、培養液のような比較的濃度の低い電解質溶液の場合、イオン交換膜としてアニオン交換膜を用いると、$t^- \fallingdotseq 1$, $t^+ \fallingdotseq 0$, カチオン交換膜では$t^+ \fallingdotseq 1$, $t^- \fallingdotseq 0$ のようにほぼ一方の電荷を持つイオンしか膜内を通ることができない。したがってイオン交換膜の両端の電位差は、

$$M^+X^-(C^{I}) \mid 膜 \mid M^+X^-(C^{II})$$

のように簡単な系を例にとると、近似的に

$$E_m^+ \fallingdotseq -\frac{RT}{F}\ell n \frac{C^{I}_{M^+}}{C^{II}_{M^+}}$$

……カチオン交換膜

$$E_m^- \fallingdotseq \frac{RT}{F}\ell n \frac{C^{I}_{X^-}}{C^{II}_{X^-}}$$

……アニオン交換膜

で表わされ、両溶液間の濃度比の対数に比例した膜電位差が生ずる。上式のように単純な濃度差の場合は$|E_m^+| \fallingdotseq |E_m^-|$という関係が得られる。しかしながら、もし$M^+X^-(C^{II})$のバランスが何かの原因でくずれ、$M^+X^-(C^{II}-\alpha) + M^+Y^-(\alpha)$となった場合は、（ただし$Y^-$はアニオン交換膜を

通らないとする）

$$E_{m^+} \fallingdotseq -\frac{RT}{F}\ell n\frac{C^{I}_{M^+}}{C^{II}_{M^+}}$$

$$E_{m^-} \fallingdotseq \frac{RT}{F}\ell n\frac{C^{I}_{x^-}}{C^{II-\alpha}_{x^-}}$$

となり、もはや $|E_{m^+}| \fallingdotseq |E_{m^-}|$ の関係は成立しなくなる。

培養液のPH値が作物栽培の過程において変化する原因は上記の理由によるものである。すなわち、植物の根からの栄養源である無機イオンを $Ca(NO_3)_2\cdot 4H_2O\cdot MgSO_4\cdot 7H_2O$, KNO_3, $NH_4H_2PO_4$ 等の中性塩の形で規定量水に溶解させて培養液を調整した段階においては、これら無機イオンは、カチオンおよびアニオン等量ずつ含まれている。栽培の過程で植物根はこれら無機イオンを中性塩の形で化学量論的に吸収するものではなく、たとえばある生育ステージでは NO_3^- イオンのようなアニオンをまた他の生育ステージでは Ca^{++} や K^+ のようなカチオンをと云ったように培養液組成から見て吸収のアンバランスを生ずる。したがって、培養液中に含まれる無機イオンの化学量論式は、最初水に溶解した無機の中性塩の形では成立せず、水の解離イオン H^+ と OH^- のバランスすなわち、PHの変動により培養液中の電気的な中性が保たれる。このように培養液が基準培養液にくらべて単純な濃度減少だけでなく、上記のような組成変化すなわちPH変化をも伴った濃度減少を起した場合は、基準培養液との間にイオン交換膜を介したときの膜電位差、アニオン交換膜を介したとき E_{m-} とカチオン交換膜を介したとき E_{m+} とが異なってくる。

以上のように膜電位差を利用することにより、培養液の濃度変化量およびPH変動量を電位差として検出することができ理想的な培養液組成の自動管理が可能になる。

培養液として一般的に用いられている以下の中性塩の組合せを基準として、各組成変化に伴う膜電位差を調べたところ、次の表のような結果を得た。

基準培養液濃度
$MgSO_4\cdot 7H_2O$ … 4 me/ℓ, $Ca(NO_3)_2\cdot 4H_2O$ … 8 me/ℓ
KNO_3 …… 8 me/ℓ, $NH_4H_2PO_4$ …… 4 me/ℓ
照合電極 Ag/AgClℓ電極

基準培養液に対する濃度比および組成比		膜電位差(mV)(基準培養液に対する電位) カチオン交換膜	アニオン交換膜
1	均等組成	0	0
	K^+ を0.25me/ℓ減 PH5.4	−0.24mV	−0.02
	SO_4^{2-} を0.25me/ℓ減 PH7.0	0	+0.23mV
0.90	均等組成	−2.06	+2.06
	K^+ を0.25me/ℓ減 PH 6.3	−2.35	+2.04
	SO_4^{2-} を0.25me/ℓ減 PH 7.1	−2.06	+2.34
0.80	均等組成	−4.94	+4.93
	K^+ を0.25me/ℓ減 PH 6.1	−5.51	+4.90
	SO_4^{2-} を0.25me/ℓ減 PH 7.3	−4.92	+5.49

上の表のように、2種類のイオン交換膜の膜電位を測定することにより、0.1 mV 以下の精度で基準培養液からの濃度減少およびその時の培養液組成が瞬時に調べられる。

次に本発明による培養液組成自動調整装置の実施例を図面を参考に説明する。1は培養液槽で、培養液槽1中の培養液2はポンプ3により連続的に、またはタイマ4の操作により間欠的に培養液供給管5を経て、栽培槽6に供給され、還流管7を通って再び培養液槽1に戻ってくる。この過程において培養液2中の各栄養成分は栽培槽6中の作物に吸収されるため、培養液槽1で液面調節器8により液面を一定に保たれた培養液2中の栄養成分濃度が次第に減少すると共に、組成バランスもくずれてPHが変化する。これら変化を検出するためにAg/AgClℓ電極,甘こう電極，酸化物電極等のうち3本の同種照合電極9，10，11を用い、そのうちの1本の照合電極10はイオン交換膜としてのカチオン交換膜31およびアニオン交換膜32が互に接することなく壁を構成しかつ栽培対象作

物に最適組成の基準培養液１２で満たされ、さらにこれらイオン交換膜壁が培養液２と接するように培養液槽１中に備えられている容器１３中に浸漬し、他の２本の照合電極９，１１はこれらイオン交換膜壁を介して容器中の照合電極１０とそれぞれ対向するように培養液２中に浸漬して上記カチオン交換膜３１およびアニオン交換膜３２各々の膜壁を介して両照合電極９，１０間および照合電極１０，１１間の膜電位差を検出する。そして前記表に示したように培養液２に組成変化があれば、それに対応して発生した膜電位差は各々の照合電極９，１０，１１のリード１４，１５，１６を通って組成調節器17に伝えられる。もしカチオンについての膜電位差である照合電極９，１０間の電位差とアニオンについての膜電位差である照合電極１０，１１間の電位差の絶対値に差があり、その値が補正を必要とするような組成変化であれば、たとえば照合電極９，１０間の電位差の方が大きく、すなわち組成バランスがくずれて培養液のPHが酸性側にある場合は、組成調節器１７からの信号により、ポンプ３より汲み上げられた培養液２を培養液供給管５の途中を分枝して設けられ、中に陰イオン交換樹脂が充填されたカラム18を通過させ培養液２のPH を上昇させて培養液槽１に戻すように電磁弁１９を作動させ、反対にアニオン膜電位である照合電極１０，１１間の電位差の方が大きいとき、すなわち培養液２のPH がアルカリ性側に寄った場合は、組成調節器１７からの信号により電磁弁２１を作動させ、培養液２を、陽イオン交換樹脂が充填されたカラム２０中に通してPH を下げるというように、培養液２のPH 調節のための電磁弁１９または２１を作動させるような信号を組成調節器１７より出す。これと並行して培養液濃度の減少度合を表わす照合電極９，１０間および照合電極１０，１１間の２つの膜電位差のどちらか一方または両方を平均した電位差を検出し、もし補正を必要とするような培養液濃度の減少があれば、組成調節器１７からの信号で原液タンク２２，２３，２４の電磁弁２５，２６，２７を開き、原液を培養液槽１に供給しながらモータ２８によって駆動された撹拌器２９により培養液２を均一にする。

以上のような操作により、照合電極９，１０間および照合電極１０，１１の両電位差間の差、及び両電位差そのものの値が許される範囲で小さくなれば、各電磁弁１９，２１および２５，２６，２７は組成調節器１７の信号により全て閉じられ、培養液２の組成は基準培養液１２の組成とほぼ等しく補正されたことになる。もし対象作物がその生育ステージにより培養液の最適組成が変化するものであれば、容器１３内の基準培養液１２は生育ステージ毎に最適組成の培養液に入れ換えることにより、培養液２の組成を自動的に調整することができる。

上記実施例では培養液２の組成変化を検出する手段として、同種の３本の照合電極９，１０，11と対象作物の生育に最適の基準培養液１２で満たされ、かつカチオン交換膜３１およびアニオン交換膜３２が互に接することなく壁を構成した容器１３による場合、すなわち、第２図(ハ)で表される構成によっていたが、第２図(ロ)に示すように同じ容器１３中に２本の照合電極１０，10′を用いた検出手段、あるいは第２図(ハ)に示すように、極性の異るイオン交換膜壁を２つの容器１３，13′に分離し、照合電極９，１０およびカチオン交換膜３１を有する容器１３の構成でカチオン膜電位差を検出し、照合電極１０′，11およびアニオン交換膜３２を有する容器１３′でアニオン膜電位差を検出するようにしてもよい。

なお、第３図に培養液組成調節器１７の制御例を示す。すなわち、第１図および第２図で示されるように、検出端により検出されたカチオン交換膜電位差V_Kおよびアニオン交換膜電位差V_Aは各々インピーダンス変換器３３，３４を通して安定化されたのち、絶対値増巾器３５，３６を通して電位の符号を等しくする。処理された２つの電位を減算器３７に通し、もしPH 補正を必要とする程両電位差に差があれば、２つのヒステリシスコンパレータ３９，４０のうちどちらか１つによりPH を上げるかまたはPH を下げる信号を出す。

それと同時に処理された２つの電位は加算器３８に入り両電位差の平均値の電位差を３つめのヒステリシスコンパレータ４１に伝え、もし濃度補正を必要とするような電位差であれば原液タンク22，２３，２４のバルブ２５，２６，２７を開く信号を出す。このようにして、培養液が許容のPH範囲に対応する両膜電位差間の差および許容濃度に対応する両膜電位差の平均電位差におさまれば、組成調節器１７からはいずれの出力信号も出なくなり、培養液組成の補正は完了する。

なお、培養液のPHを調整する方法としては、培養液をイオン交換樹脂層中を通してPHを補正する例について述べたが、その他、酸およびアルカリ補助タンクから酸またはアルカリを補給する方法や、イオン交換膜を介して電気分解を行う方法等、制御器からの電気的な信号により培養液のPHを調整し得る手段であれば、いづれも本発明による培養液組成自動調整装置に使用し得る。

上記実施例から明らかなように、本発明の培養液組成自動調整方法およびその調整装置は、培養液濃度とPHを同時に検出し、各々の補正ができるので、容積の小さい装置で安価な調整が可能となり、その工業的価値は大である。

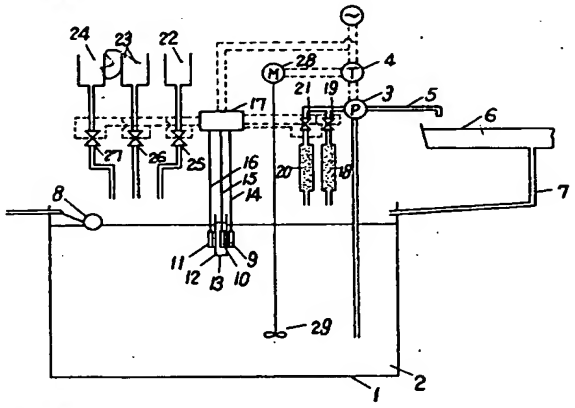
４．図面の簡単な説明

第１図は本発明の一実施例を示す培養液組成自動調整装置の構成図、第２図(イ)，(ロ)，(ハ)はそれぞれ同調整装置の培養液組成変化検出部の各種実施例を示す構成図、第３図は同調整装置の組成調節器のブロック図である。

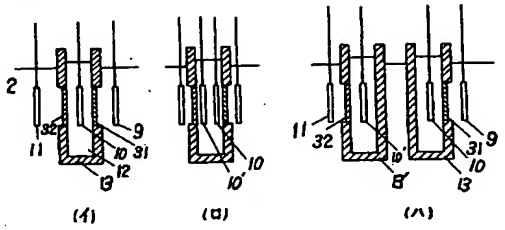
１……培養液槽、２……培養液、３……ポンプ、４……タイマ、５……培養液供給管、６……栽培槽、７……環流管、８……液面調節器、９，１０，１０′，１１……照合電極、１２……基準培養液、１３，１３′……容器、１４，１５，１６……リード、１７……組成調節器、１８，２０……カラム、１９，２１，２５，２６，２７……電磁弁、２２，２３，２４……原液タンク、３１……カチオン交換膜、３２……アニオン交換膜、３３，３４……インピーダンス変換器、３５，３６……絶対値増幅器、３７……減算器、３８……加算器、39，４０，４１……ヒステリシスコンパレータ。

代理人の氏名　弁理士　中尾敏男　ほか１名

第 1 図



第 2 図



第 3 図